FEAMAC Example 5

***Description*:**

This FEAMAC example problem involves the analysis of a composite bonded doubler joint. The joint geometry is shown in Fig. 25, and the half-symmetry finite element mesh, consisting of 21,200 CPE4 elements, is shown in Fig. 26. Unlike the previous example problems, this problem is a plane problem, utilizing plane strain elements. The loading is applied as a distributed surface load (i.e., pressure) to the end of the bottom joint adherend, as shown in Fig. 25, using the ABAQUS `*DSLOAD` specification. The adherend materials are a 25% particulate SiC/Ti composite represented by a triply-periodic 2×2×2 GMC repeating unit cell. The adhesive material is not represented by MAC/GMC, but rather as an isotropic nonlinear Ramberg-Osgood material. This is accomplished via the `*Deformation Plasticity` specification in the ABAQUS input file. The Ramberg-Osgood material response is given by the following equation (for the uniaxial case),

$$E\varepsilon = \sigma + \alpha\left(\frac{|\sigma|}{\sigma_0}\right)^{n-1}\sigma$$

where σ is the stress, ε is the strain, E is the elastic modulus, and α, σ_0, and n are material parameters. These material parameters, along with a plot of the unixial nonlinear response they represent, are given in Fig. 27. Because this problem involves a larger number of elements, the loading had been applied in a single step. Even so, the execution time and memory requirements for the problem are greater than the other example problems.

Required Files:

The following files should be placed in the ABAQUS working directory:

File	**Purpose**
`feamac_ex5.inp`	ABAQUS input file
`SiC-Ti_25p.mac`	MAC/GMC input file describing the particulate SiC/Ti composite material
`feamac.for`	User-defined subroutines for FEAMAC

Note that the `SiC-Ti_25p.mac` MAC/GMC input file utilizes material properties in ksi units, while the `feamac_ex5.inp` ABAQUS input file utilizes length units of meters and pressure units of Pa. The `*CONVERT` specification has thus been employed in the MAC/GMC input file with a specified conversion factor of 6.895×10^6 Pa/ksi. This will cause the MAC/GMC stress and stiffness components, which are in ksi, to be multiplied by 6.895×10^6 Pa /ksi before they are passed to ABAQUS. As such, the ABAQUS-level results will be output in units of Pa, while the MAC/GMC-level results will be output in ksi.

Execution:

This problem can be executed via the following command at the ABAQUS command line:

```
abaqus –j feamac_ex5 –user feamac interactive
```

The `–j` specification indicates the job name (i.e., ABAQUS input file name), while the `–user` specification indicates the file containing the FEAMAC user-defined subroutines. The `interactive` specification provides detailed information on the problem execution during the execution and is optional.

Output:

The output for this problem is written to the ABAQUS output database file `feamac_ex5.odb` for post-processing in ABAQUS/CAE, ABAQUS/Viewer, or other appropriate finite element post-processing software. No MAC/GMC xy plot data output is written in this problem. A MAC/GMC output file, `SiC-Ti_25p.out`, is also written.

Results:

Results for the bonded doubler joint in the form of plots of the von Mises stress throughout the joint and the equivalent plastic strain in the adhesive are given in Figs. 28 and 29. The stresses are highest in the middle of the joint near the lower surface of the bottom adherend, but the applied loading is not sufficient to yield the composite adherends. It is thus noted that identical results could be obtained by utilizing effective elastic properties for the particulate composite material rather than using FEAMAC. Marked nonlinear material behavior is evident in the adhesive near the bond free edge. Fig. 30 is a plot of the adhesive peel and shear stresses along the middle of the adhesive (see Fig. 31). The typical concentration in peel stress just inside the bond edge is evident.

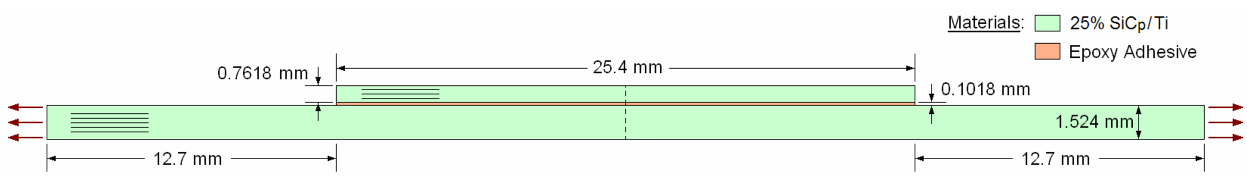

Fig. 25. Geometry, dimensions, and materials for the bonded doubler joint.

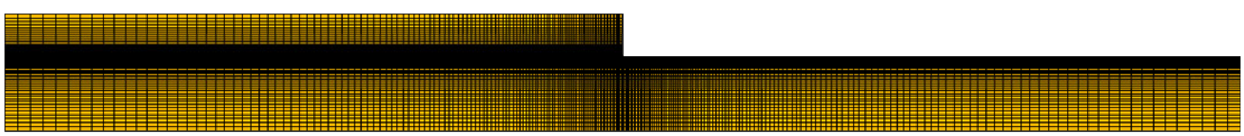

Fig. 26. Half-symmetry ABAQUS finite element mesh consisting of 21,200 CPE4 elements.

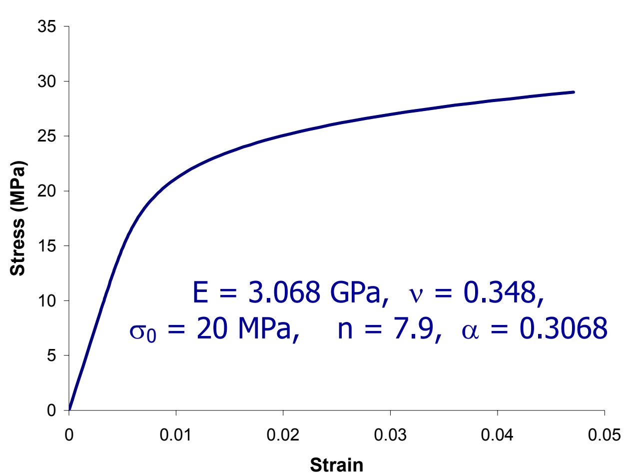

Fig. 27. Isotropic Ramberg-Osgood nonlinear material constitutive response employed for the adhesive.

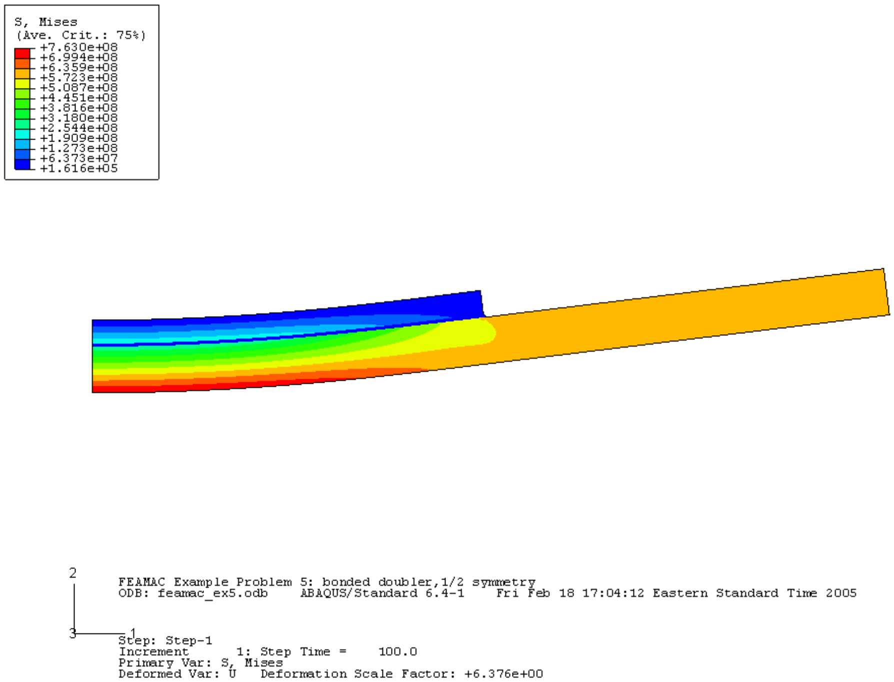

Fig. 28. von Mises stress field (Pa) in the bonded double joint as predicted by FEAMAC.

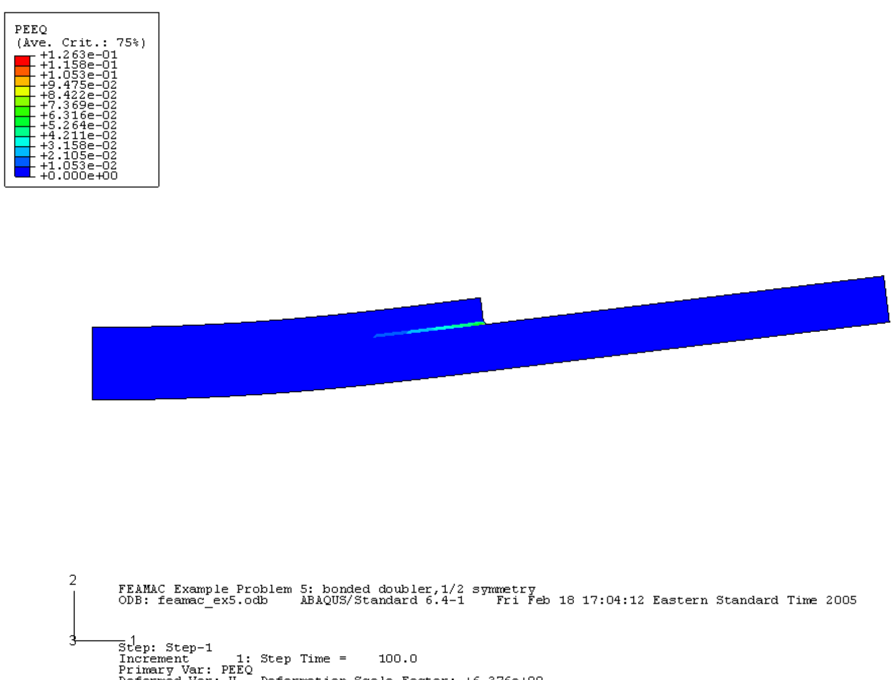

Fig. 29. von Mises stress field (Pa) in the bonded double joint as predicted by FEAMAC.

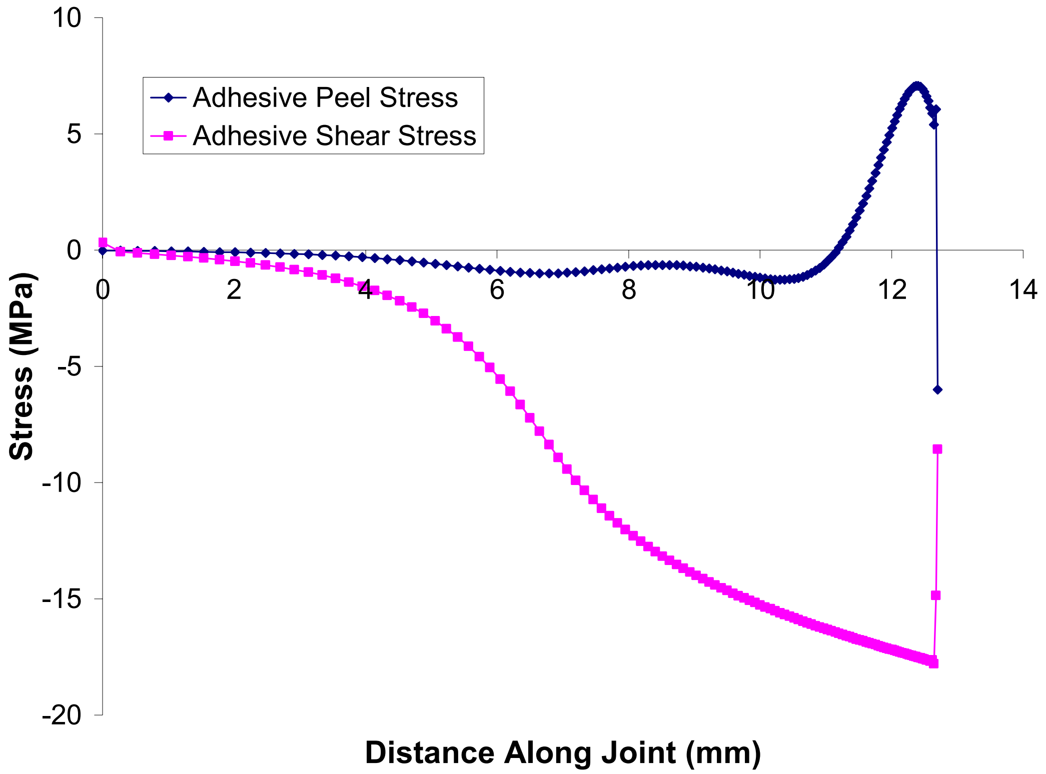

Fig. 30. Adhesive stresses along the bonded doubler joint (see Fig. 31) as predicted by FEAMAC.

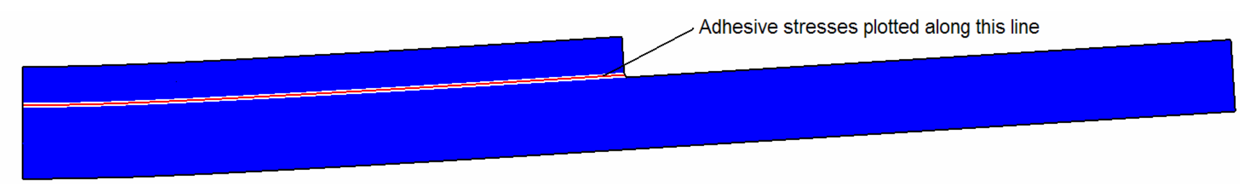

Fig. 31. Line (mid-adhesive) along which the adhesive stresses are plotted in Fig. 30.